§3. A Feedback Control of Hydrogen Pump Using a High-temperature Proton Conductor for Tritium Recovery System

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In a future nuclear fusion plant, hydrogen isotope gas of deuterium (D) and tritium (T) is used as fuel. The developments of hydrogen process technologies for fuel cycle are one of the important issues. An electrochemical hydrogen pump using a proton-conducting oxide is one of the candidate materials for hydrogen recovery. The application of electrochemical hydrogen pump by a proton conducting oxide instead of the palladium membrane diffuser has been proposed. In our previous research, we have chosen $CaZr_{0.9}In_{0.1}O_{3-\alpha}$, which was used for the one-end closed tube of the test pump. Then, the hydrogen pump performances were investigated under various conditions. During the hydrogen pump experiments over a long period of time, the variations of applied current or voltage and hydrogen extraction rate were observed. It is likely that the proton conductor as oxide material is reduced by the extracted hydrogen. Then, the properties such as conductivity and solubility of proton might be changed by the reduction reaction. To realize the hydrogen recovery system using proton conductor, it is necessary to maintain the hydrogen pumping performance at a constant value. Therefore we propose the application of a feed back control system to hydrogen pump.

We carried out the performance tests by use of the one end closed tube made of $CaZr_{0.9}In_{0.1}O_{3-\alpha}$ under water vapor electrolysis condition. The shape of the test tube was 12 mm inner diameter, 0.75 mm thickness and 200 mm length. Platinum electrodes were attached on both sides of the test tube by paste-baking on the surface. The test tube was heated from 873 K by an electric furnace. Wet argon of 1.2 kPa was fed to the anode and dry argon was fed to the cathode. These flow rates were 100 cm^3/min. The hydrogen pumping experiments was conducted by the constant current method using a galvanostat. Then, the gas in the stream was measured by a gas chromatograph and a chilled mirror hygrometer. To maintain a hydrogen extraction rate, a standard proportional-integral-differential (PID) control method is introduced. The block diagram of PID control is shown in Fig.1. When the dew point at the outlet of anode compartment is changed, the PID controller generates the control output signal of the difference between set and present dew point in order to change applied current. The control output signal m(t), which represents applied current, is a sum of three terms, the proportional term, the integral term, and the derivative term. Each of these terms is a function of the error signal e(t), which represents difference between set and present dew point. Mathematically proportional-integral-differential (PID) control is expressed as follow:

$$m(t) = K_p e(t) + K_i \int_0^t e(\tau)d\tau + K_d \frac{de(t)}{dt}$$

To prevent the proton conductor from deterioration by extremely high current and voltage, the upper limit of current or voltage as a saturation block was set under PID control operation. The PID control and data acquisition system was produced by NI-DAQ and LabVIEW program.

Figure 2 shows the variations of applied current, voltage, hydrogen concentration at cathode, dew point at anode under the feedback control. The control period was 15 seconds. The control parameters of K_p, K_i, K_d estimated by the Ziegler-Nichols step response method were 10, 4, 0.25. The upper limits of current and voltage were 0.3A and 5 V. When the set value of dew point was changed in steps, the applied current was changed by PID control according to the difference between the dew point of set and present value. Then, the dew point and hydrogen concentration in the cathode compartment were reached at a constant after few minutes. In this case, the over and under shoot in the applied current was observed immediately after changing the set value. However, the range of over and under shoot was not large in these steps. It is likely that good current control can be obtained on the whole. On the other hands, when the set value of dew point was changed from 10 °C to 2 °C by one step, the applied current reached the upper limit and the protective circuit of saturation block worked. The parameters of PID control have to optimize and are properly used depending on the operation.

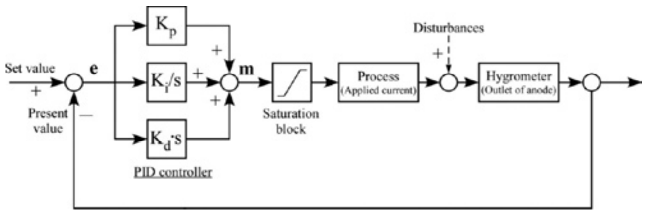

Fig. 1. A schematic flow diagram of PID feedback control system.

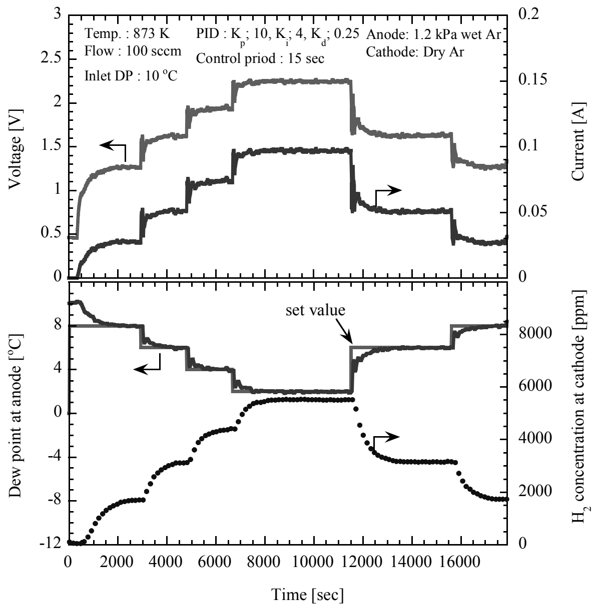

Fig. 2. Variations of voltage, applied current, dew point at the anode, and hydrogen concentration at the cathode under the feedback control.